How can batteries 'fuel' the built environment?

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Abstract

This study has been undertaken to gain a better understanding of how battery systems can contribute to the design of a future built environment where renewable energy systems will play a significant role. This paper provides design considerations for battery storage integration in buildings, emphasising on their spatial requirements. An analysis has been undertaken to assess the footprint, the volume, the weight as well as the investment cost of eight different battery technologies able to electrically supply a house in the UK. The house is assumed to be powered by renewable energy sources (RES), is able to operate off-grid and is electrically heated. Three scenarios have been explored in order to assess the spatial requirements of each of the battery technologies in 2030. It is concluded that Li-ion, Zn-air and NaNiCl battery technologies are the most favourable options for electrical energy storage (EES) integration in buildings in all 2030 scenarios due to their small footprint, small volume and low weight. Cost-wise Li-ion batteries currently have the highest investment cost, but are expected to be a cost competitive option in 2030.

1. Introduction - Contribution of EES in the built environment

In the last two decades, sustainability and the irreversible depletion of natural resources has been the subject of constant debate on a global scale. Greenhouse gas emissions coming from energy-related activities accounted for 68% of the global greenhouse gas emissions in 2005 (International Energy Agency, 2012). The building sector is found to be in charge of over 40% of the total energy consumption in Europe (World Business Council for Sustainable Development, 2010). Identifying opportunities to reduce this consumption has become a priority in the global effort to deal with climate change. In addition, a very ambitious target set by the EU entails a significant CO_2 reduction by 80 to 95% by 2050 compared to 1990 levels (European Commission, 2011, European Wind Energy Association, 2011, European Commission, 2010). Hence, the establishment of eco-design requirements for buildings, services and products is central to the challenge of sustainability and the mitigation of climate change.

An **increasing demand** in the electricity sector is anticipated in the upcoming years due to the extension of the electrification of the population worldwide, the increase in energy consumption due to economic growth, the use of electrical energy for heating and cooling and the use of electricity in the transport sector (Department of Energy and Climate Change, 2011). The remaining reserves of the non-renewable energy resources currently in use, such as coal, oil and gas, are continuously decreasing and it is questionable whether their capacity will be able to meet rising demand levels. Thus, electricity generation from renewable energy sources, such as the sun and the wind, are already at the forefront of sustainable energy planning and are expected to play a central role in the low carbon future (International Energy Agency, 2013). Following the increasing deployment of renewable energy technologies, as shown in **Figure 1**, EES is considered to be one of the key components of the built environment in the future (Inage, 2011, Sandu-Loisel and Mercier, 2011).

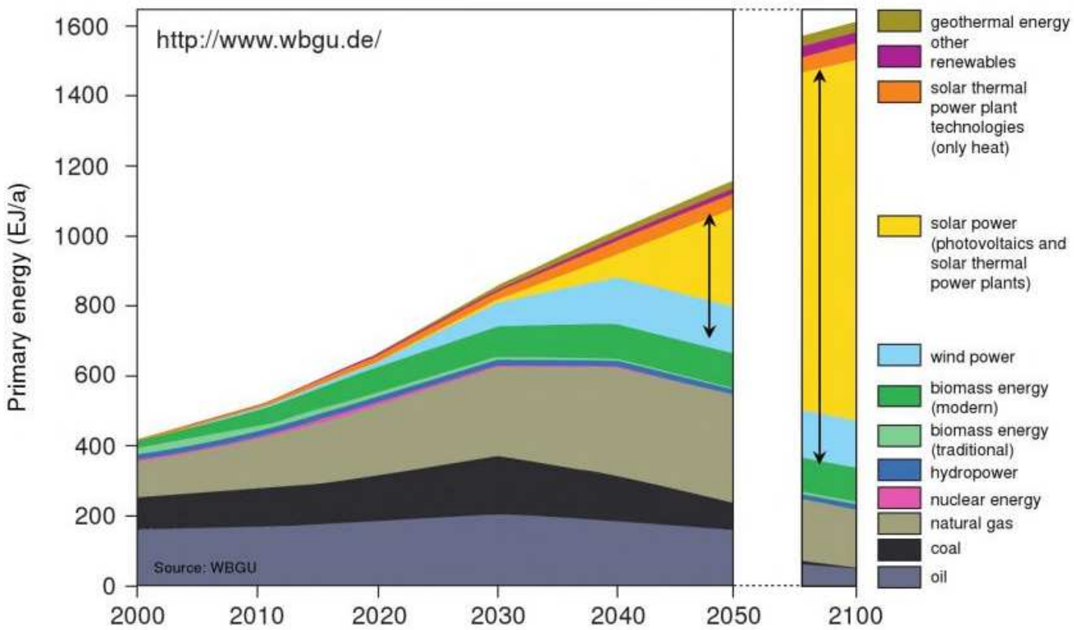

Figure 1: Scenario for a worldwide energy mix in the next decades (German Advisory Council on Global Change, 2008, Droege, 2008)

Storage has always played a critical role in traditional energy markets, as the currently dominant fossil fuels –coal, oil and gas– have always been traded within commodity markets in the same way that coffee and metals have (Naish et al., 2008). Traditional primary sources of electricity generation store energy on site in the form of a stock; this can be coal, oil, gas or even water behind a dam. The key requirement for the electricity network to operate efficiently is the instantaneous match of supply and demand. If this fails to happen, blackouts and other severe consequences might occur.

The importance of EES lies in the fact that most forms of low or zero carbon energy generation that will be used in the future are fundamentally different in nature from the traditional fossil fuels currently used for electricity generation (Naish et al., 2008). Electricity in the low carbon future will primarily come from either renewable or nuclear fuels (Massoud, 2013). Nuclear generation is typically designed to operate at a constant output, but renewable generation is most times intermittent, meaning that it has a variable output. Therefore, the instantaneous match of supply and demand will be difficult to achieve under these variable circumstances.

EES provides the possibility to store electrical energy when it is generated from the intermittent renewable sources, for example solar and wind, in order for it to be available when needed. In this way, electricity supply can match load demand on a constant basis, providing the necessary stability to the electrical grid (Electricity Advisory Committee, 2012). In addition, EES solutions can be applied at all levels of the electricity system (The Electricity Storage Network, 2014), influencing generation and consumption. Depending on their location in the system, they are capable of providing diverse benefits (Teller et al., 2013), which are summarised in **Table 1**.

Table 1: EES applications at different levels of the electrical system (Teller et al., 2013)

Generation level	Arbitrage, capacity firming, curtailment reduction
Transmission level	Frequency and voltage control, investment deferral, curtailment reduction, black starting
Distribution level	Voltage control, capacity support, curtailment reduction
Customer level	Peak shaving, time of use cost management, off-grid supply

UK has recently started actively demonstrating, installing or planning EES applications. A capacity of 5.1 MW and 6.4 MWh was commissioned in November 2013, with an additional 7.2 MW and 13.8 MWh either under construction or being planned (Lang et al., 2013). Two recent case studies of battery integration at residential level are SoLa Bristol and Zero Carbon Homes (ZCH). SoLa Bistol project's aim is to address the technical constraints that DNOs expect to arise on Low Voltage networks as a result of the increased adoption of solar PV (Kaushik, 2014). A 4.8kWh Pb-acid (Lead-acid) battery bank along with a 2kWp solar photovoltaic (PV) installation are installed in each of thirty homes in Bristol (Kaushik, 2014). The electricity generated by the PV on the roof of the houses is stored locally in the batteries, instead of being exported to the grid. This allows customers to make the best use of their own generation. As regards the location of the battery installation, the lofts of the houses were identified as appropriate to house the equipment.

As for the ZCH project, three 25kW/25kWh Li-ion (Lithium-ion) batteries connected to the Low Voltage network have been installed by SSE to power a development of 10 homes in Slough (Steele and MacLeman, 2014). The south-facing roofs of the homes have been covered with solar PV tiles, totalling a solar installed capacity of 63kWp. This capacity provides enough renewable electricity to achieve net zero carbon emissions in each of the homes, irrespective of heat source. The three battery units will help explore if they are capable of mitigating the effects of potential load increases, as well as the consequences from the deployment of low carbon technologies in buildings. The batteries are located outdoors in a protected area close to the housing development.

An example of an off-grid building in Wales is the three-bed farmhouse in Caerphilly, UK, which has been hailed as an exemplar of sustainable building excellence (ThermaSkirt, 2015). It is supplied with a 3.9kWp solar PV array integrated in the south facing roof and a Pb-acid battery bank located in the basement. The panels provide power throughout the day and any surplus charges the batteries for hours of darkness. The battery bank stores 42kWh and if this dips below 40% a 10kW back-up diesel generator takes over to provide the necessary power. The battery rooms of the three case studies discussed above are shown in **Figure 2**.

Figure 2: Battery rooms of SoLa Bristol, ZCH and Maes Yr Onn project

2. Contribution aspects and EES technologies in the built environment

There are two characteristics of electricity that currently have an impact on its use and basically generate the need for the introduction of EES in the built environment.

The first one is that **electricity consumption occurs at the same time as electricity generation**. The demand varies over time and electricity supply should match this varying demand (**Figure 3**). Due to the variation in demand, there is a variation in the cost of generation, too. Hence, the price of electricity is higher at peak-demand periods and lower at off-peak demand periods (Electricity Advisory Committee, 2012). Storage facilities in this case could enable the reduction of the generation costs, as they could store low-cost electricity generated during nighttime and release it to the power grid during peak periods. Consumers could also benefit financially by storing electricity generated during off-peak hours and then either using it or selling it to utilities or other consumers during peak periods (International Electrotechnical Commission, 2011).

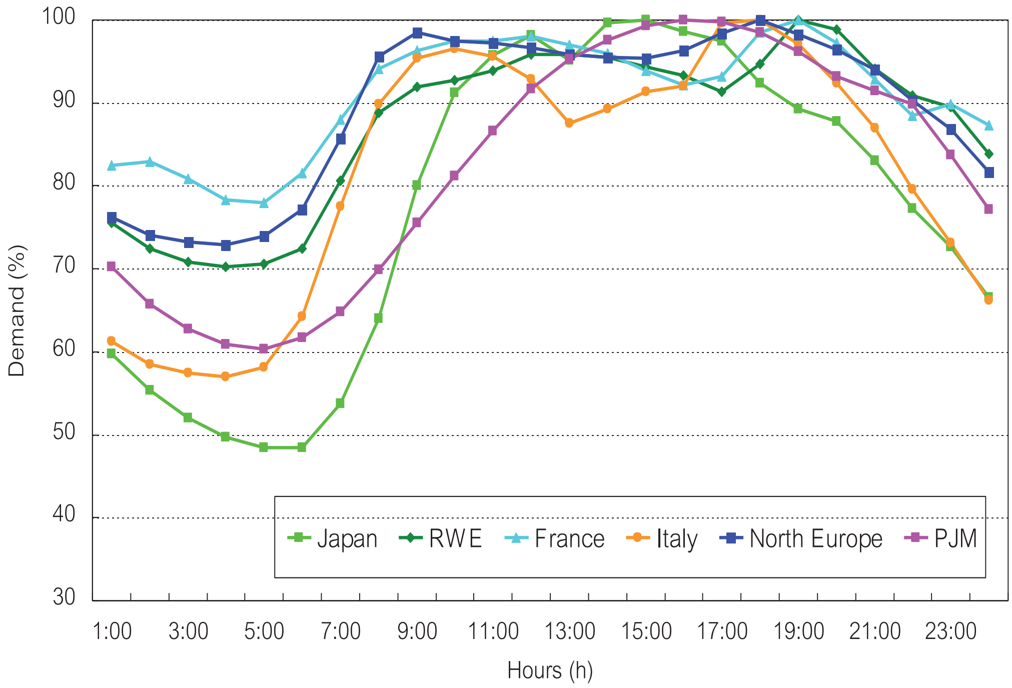

Figure 3: Comparison of daily load curves (International Electrotechnical Commission, 2011)

Also, **electricity is usually generated far from the locations where it is consumed**, which forms the second fundamental characteristic. The farther the consumption and generation locations, the higher the chances of an undesirable interruption in the power supply. Wide areas could also potentially be affected by power network failures. The long distance between generation and consumption can result in power congestion, as the power transmission lines can get heavily loaded due to high demand (Electricity Advisory Committee, 2012). Moreover, powering remote areas and mobile applications can present difficulties, as the transmission of electricity always requires appropriate cabling (International Electrotechnical Commission, 2011).

Electricity storage could be helpful in all the above cases. It could, therefore, ensure the continuity of power supply to consumers, acting as emergency resource when, for example, voltage sags occur (International Electrotechnical Commission, 2011). EES facilities can also mitigate congestion by storing electricity when transmission lines hold enough capacity and by supplying it back to the grid when congestion occurs. With regard to RES powered isolated areas and mobile applications, EES systems such as batteries could be a favourable option for electricity supply, due to their mobile and charge/discharge capabilities.

There is a fundamental difference between the impact of EES when it is used to deal with RES intermittencies and the impact of EES on energy supply, as described in the two electricity characteristics above. In the first case, they might not be able to constantly match supply and demand, as the RES output might be highly unpredictable in certain locations and low at times. In the second case this limitation does not exist, as constantly available grid electricity is stored. Another limitation in the first case and particularly when RES and EES are to be integrated in buildings is a possible lack of appropriate space for the installation of solar PV panels, due to their orientation or building form.

EES technologies exhibit a range of power and energy requirements, as well as discharge times. These are presented in **Figure 4** (International Electrotechnical Commission, 2011). The limited suggested length of this paper does not allow for a detailed discussion on the strengths and weaknesses of each technology; the reader is, therefore, advised to refer to the journal paper under the title “Characteristics of electrical energy storage technologies and their application in buildings” (Chatzivasileiadi et al., 2013).

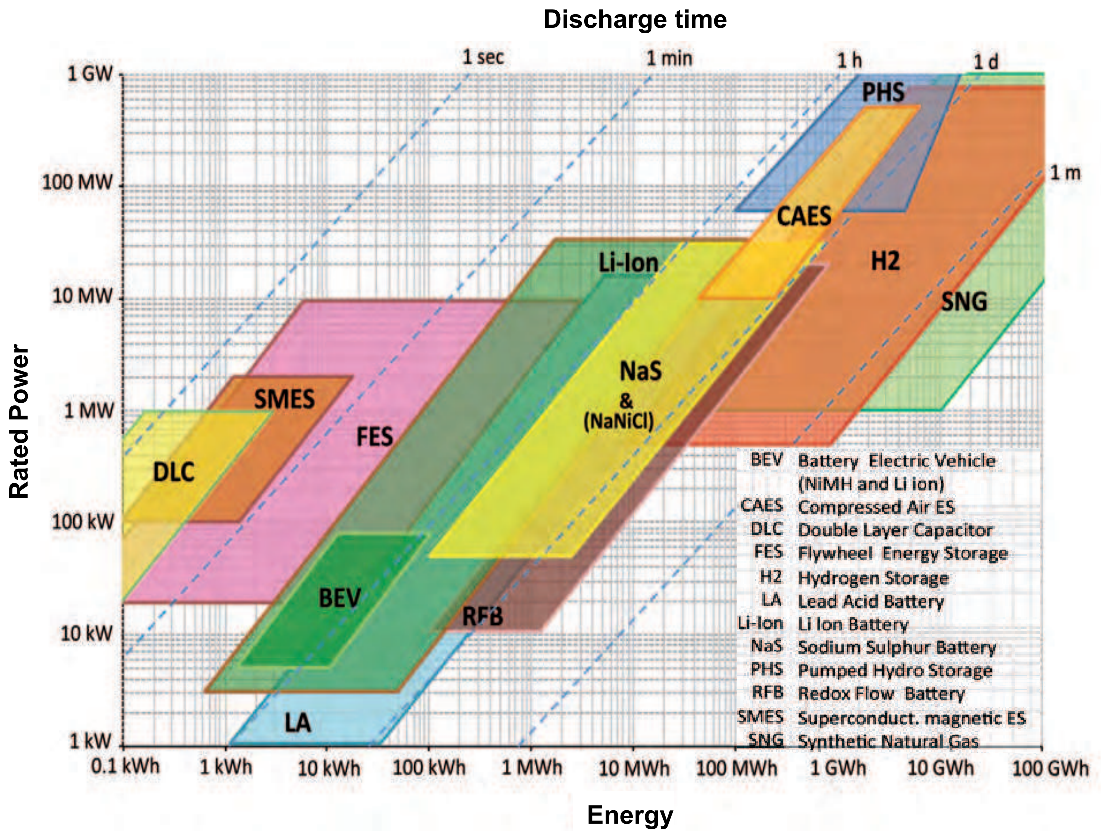

Figure 4: Comparison of rated power, energy content and discharge time of different EES technologies (International Electrotechnical Commission, 2011, Schwunk, 2011)

It is observed that the currently available types of EES technologies exhibit a large spectrum of performances and capacities to match different application environments and electricity storage scales. Not all EES systems are commercially available in the ranges shown at present, but according to the International Electrotechnical Commission (2011) all are expected to become important. The rest of the paper deals specifically with battery technologies, which are applicable at building level.

3. Battery storage design considerations

The estimation of the footprint, the volume and the weight of eight battery technologies when integrated in a single residential building in the UK in 2015 and in 2030 is presented in this section. For the 2030 values, consideration has been given to projections about the electricity consumption in the UK residential sector. Further design considerations as well as a cost analysis are also included at the end.

3.1 Daily electricity consumption

A number of electricity consumption ranges have been calculated for eight battery technologies applicable at building level in the residential sector of the UK, according to three different scenarios in 2030. Due to recent scenarios emphasizing on the likely electrification of heat in the coming years (Department of Energy and Climate Change, 2011), electric heating is assumed to take place from October to March (Department of Energy and Climate Change, 2013) in all 2030 scenarios. The investigation takes as threshold the Baseline 2015 (BS 2015) values for electricity consumption in the UK. Then the **first** scenario refers to Business as Usual (BAU 2030), where there are no major changes in the way electricity is used. What is taken into consideration though, is the impact from population and economic growth, as well as the historic trend towards increase in energy efficiency. The **second** scenario includes the implementation of energy efficiency improvements in buildings (EE 2030). The **third** scenario assumes the electrification of transport (Te 2030) on top of the assumptions for the previous scenario. One electric vehicle (EV) is assumed for one household. The assumptions for each scenario and the associated sources of information are presented in Table 2.

Table 2: Scenarios and associated assumptions

Scenarios	Assumptions	References
BS 2015	The data have been gathered and processed for weekday/weekend values from the sources on the right.	(Kreutzer and Knight, 2006) (Department for Business Enterprise and Regulatory Reform, 2008) (Department of Energy and Climate Change, 2012a) (Department of Energy and Climate Change, 2012b) (Cambell and Cambell, 2007) (Hesmondhalgh, 2012) (SP Energy Networks, 2011)
BAU 2030	+10.4%	(Department of Energy and Climate Change, 2012a)
EE 2030	-30%	(Department of Energy and Climate Change, 2012a)
Te 2030	+6kWh	From (a) and (b)
	(a) 0.16kWh/km	(Element Energy Limited, 2013)
	(b) 37km daily transport	(Melbourne, 2013)

The daily electricity consumption range for a single electrically heated household in 2015 and 2030, based on the assumptions above, is shown in Table 3. The limited suggested length of this paper does not allow for a detailed presentation of all the calculations that took place, but the reader could contact the author for further information if needed.

Table 3: Daily electricity consumption range for a single electrically heated household in 2015 and 2030 (Wd=weekday, We=weekend)

	Electricity consumption range (kWh)							
	Winter				Summer			
	Wd		We		Wd		We	
	min	max	min	max	min	max	min	max
BS 2015	8.2	21.2	9.3	22.0	5.0	12.1	6.0	13.0
BAU 2030	9.1	23.4	10.3	24.3	5.5	13.3	6.6	14.4
EE 2030	6.3	16.4	7.2	17.0	3.9	9.4	4.6	10.0
Te 2030	12.3	22.4	13.2	23.0	9.9	15.4	10.6	16.0

It is apparent that there is a high potential for electricity consumption reduction in 2030 through EE measures. Moreover, the EV at each home will hold a big share of the household consumption in 2030, adding about 25-75% to the baseline values in summer and about 30-50% in winter. The electricity consumption ranges for a single electrically heated household are illustrated in Figure 4.

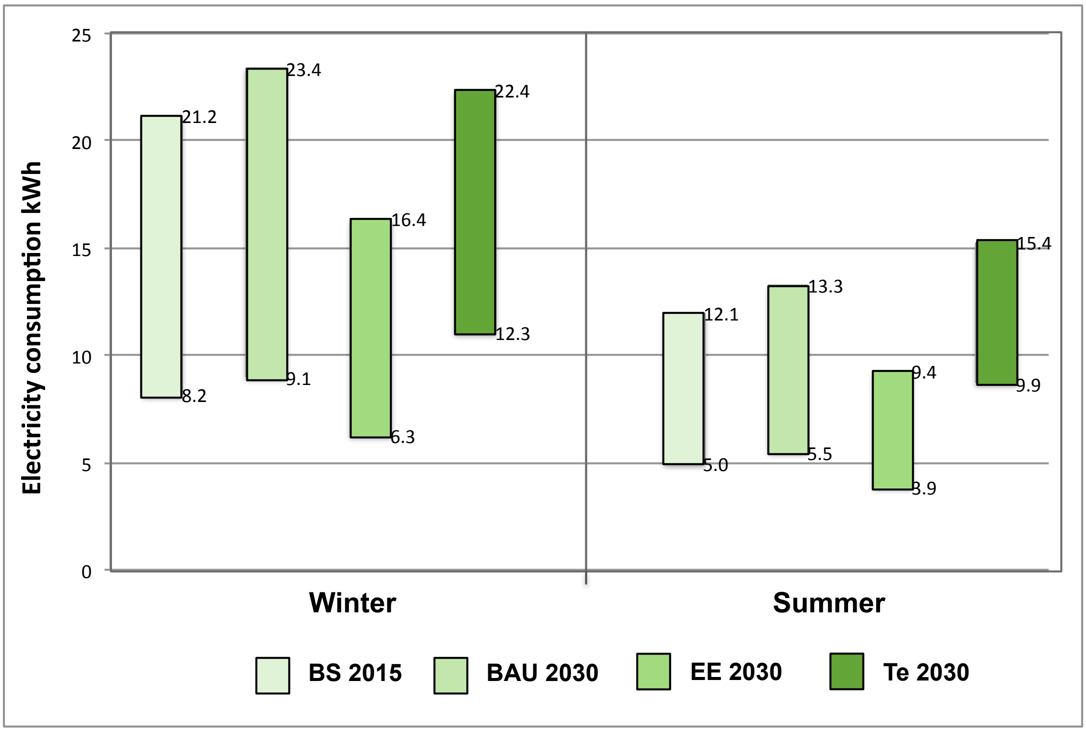

Figure 5: Daily electricity consumption range for a single electrically heated household in each scenario (weekdays)

Figure 5 shows that the electricity consumption in summer is much lower than in winter due to the lack of space heating and the lower use of lights and the oven. In addition, there is a slight increase of the electricity consumption in the BAU 2030 scenario from the baseline regardless whether winter or summer. A huge consumption decrease of 30% follows in EE 2030. Finally, in Te 2030 there is a considerable load added due to the inclusion of one EV in each household. The upper bound of the electricity consumption in this scenario for winter is lower than the consumption in the BAU case. In summer, due to the lower overall baseline household consumption, the added electrical load due to EVs is considerably high.

3.2 Sizing of the battery: storage capacity, footprint, volume and weight

The sizing of the battery system is based on winter's values, so as to allow for sufficient storage capacity all year round. In order to calculate the battery capacity for the different technologies, the following assumptions have been taken into account:

1. The house is equipped with renewable energy technologies (e.g. PV panels) and is able to operate off-grid
2. Four days of autonomy[1] for an off-grid residential system (Little, 2013)
3. Round-trip efficiency of the battery system according to the values provided in Table 4
4. 50% depth of discharge (DOD)[2]

The parameters that have been used in order to estimate the storage capacity, the footprint, the volume and the mass of the battery technologies are gathered in Table 4 and illustrated in **Figure 6**. Colour coding (related to the characteristic described in each column) has been applied in Table 4, on a red-yellow-green scale with green being the most favourable option and red the least favourable one.

[1] The days of autonomy are the days on which an off-grid house would solely rely on the electricity stored in the battery to power itself. These would be the days with minimal or no renewable energy available, e.g. minimal or no sunlight.

[2] The Depth of Discharge is used to describe how deeply the battery is discharged. Batteries should not be discharged to 100% DOD, as this would shorten the cycle life of batteries (MIT Electric Vehicle Team, 2008).

Table 4: Round-trip efficiency, spatial requirement, energy density and specific energy of the battery technologies (Chatzivasileiadi et al., 2013)

		Round-trip efficiency %	Spatial requirement m^2/kWh	Energy density kWh/m^3	Specific energy (Wh/kg)
Conventional batteries	Pb-acid	80	0.06	75	30
	NiCd	70	0.03	200	45
	NiMH	70	0.02	350	60
Advanced batteries	Li-ion	90	0.01	250	100
	NaNiCl	90	0.03	150	125
Flow batteries	V-Redox	75	0.04	20	75
	ZnBr	70	0.02	20	60
	Zn-air	60	0.005	800	400

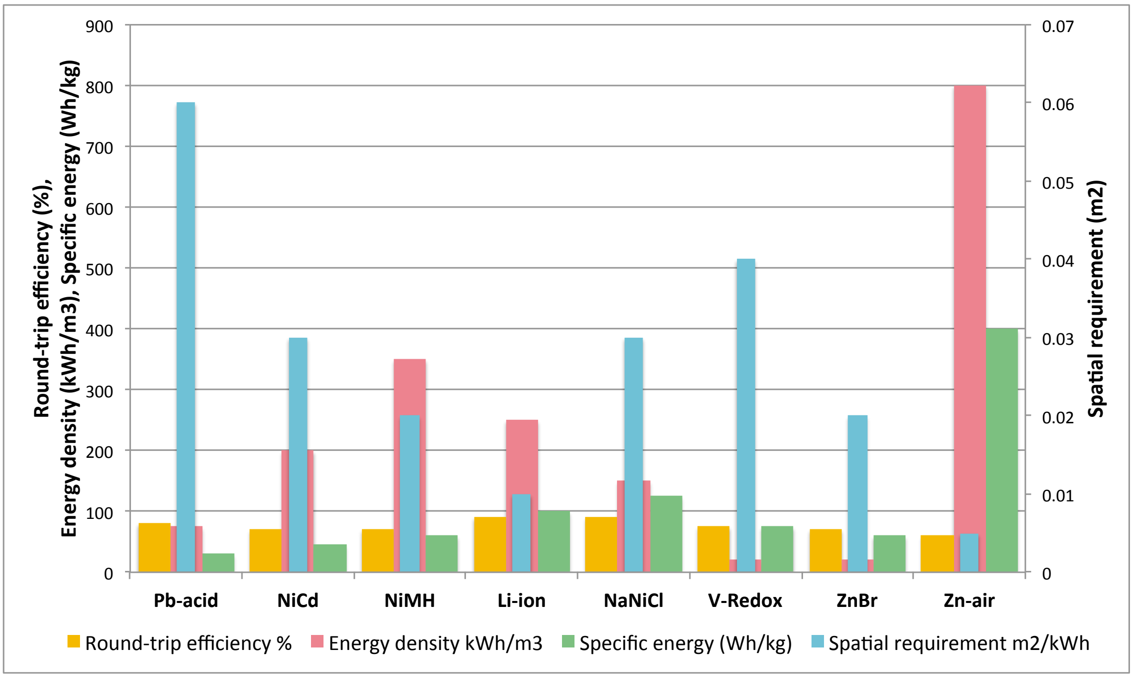

Figure 6: Battery technologies characteristics' comparison

It is observed that Li-ion and NaNiCl technologies have the highest efficiencies, while Zn-air battery the lowest. Yet the Zn-air technology scores extremely high in all the rest parameters regarding spatial requirement, energy density and specific density. Li-ion performs well in terms of spatial requirement, while NiMH and NaNiCl batteries have a high energy density and specific energy respectively. It should be noted, however, that the Li-ion technology exhibits a high potential of improved energy density and specific energy values in the future. This study has taken into account the lower bound of the range for these parameters found in the literature, so as to design for the worst-case scenario. The formula used to calculate the battery capacity (C_{bank}) is given below:

$$
\begin{aligned}
C_{bank} &= E \times 1/\eta \times 4 \text{ days} \times 100/50 \\
&= (E_{we} \times 1/\eta \times 2 \text{ days} \times 100/50) + (E_{wd} \times 1/\eta \times 2 \text{ days} \times 100/50) \\
&= (E_{we} + E_{wd}) \times 1/\eta \times 2 \text{ days} \times 100/50 \qquad (1)
\end{aligned}
$$

where E is the daily electricity consumption in winter, as shown in Table 3
η is the round-trip efficiency of the battery
E_{we} is the electricity consumption (kWh) on a weekend day
E_{wd} is the electricity consumption (kWh) on a weekday

After calculating the storage capacity for each technology using *(1)*, the values in Table 4 have been used to calculate the footprint, the volume and the mass of the battery packs. The storage capacity, footprint, volume and weight for the different battery technologies are presented in Table 5. Colour coding has been applied, on a red-yellow-green scale with green being the most favourable option and red the least favourable one. The footprint, the volume and the mass of the battery packs are also illustrated in **Figure 7**.

Table 5: Electricity storage capacity, footprint, volume and weight of the battery technologies for a single electrically heated household in each scenario

	Battery capacity requirement (kWh)							
	BS 2015		BAU 2030		EE 2030		Te 2030	
	min	max	min	max	min	max	min	max
Pb-acid	88	216	97	238	68	167	128	227
NiCd	100	247	110	272	77	191	146	259
NiMH	100	247	110	272	77	191	146	259
Li-ion	78	192	86	212	60	148	113	202
NaNiCl	78	192	86	212	60	148	113	202
V-Redox	93	230	103	254	72	178	136	242
ZnBr	100	247	110	272	77	191	146	259
Zn-air	117	288	129	318	90	223	170	303

	Battery footprint requirement (m2)							
	BS 2015		BAU 2030		EE 2030		Te 2030	
	min	max	min	max	min	max	min	max
Pb-acid	5.3	13.0	5.8	14.3	4.1	10.0	7.7	13.6
NiCd	3.0	7.4	3.3	8.2	2.3	5.7	4.4	7.8
NiMH	2.0	4.9	2.2	5.4	1.5	3.8	2.9	5.2
Li-ion	0.8	1.9	0.9	2.1	0.6	1.5	1.1	2.0
NaNiCl	2.3	5.8	2.6	6.4	1.8	4.4	3.4	6.0
V-Redox	3.7	9.2	4.1	10.2	2.9	7.1	5.4	9.7
ZnBr	2.0	4.9	2.2	5.4	1.5	3.8	2.9	5.2
Zn-air	0.6	1.4	0.6	1.6	0.5	1.1	0.9	1.5

	Battery volume requirement (m3)							
	BS 2015		BAU 2030		EE 2030		Te 2030	
	min	max	min	max	min	max	min	max
Pb-acid	1.2	2.9	1.3	3.2	0.9	2.2	1.7	3.0
NiCd	0.5	1.2	0.6	1.4	0.4	1.0	0.7	1.3
NiMH	0.3	0.7	0.3	0.8	0.2	0.5	0.4	0.7
Li-ion	0.3	0.8	0.3	0.8	0.2	0.6	0.5	0.8
NaNiCl	0.5	1.3	0.6	1.4	0.4	1.0	0.8	1.3
V-Redox	4.7	11.5	5.1	12.7	3.6	8.9	6.8	12.1
ZnBr	5.0	12.3	5.5	13.6	3.9	9.5	7.3	13.0
Zn-air	0.1	0.4	0.2	0.4	0.1	0.3	0.2	0.4

	Battery weight (kg)							
	BS 2015		BAU 2030		EE 2030		Te 2030	
	min	max	min	max	min	max	min	max
Pb-acid	2,917	7,200	3,220	7,949	2,254	5,564	4,254	7,564
NiCd	2,221	5,482	2,451	6,052	1,716	4,236	3,239	5,759
NiMH	1,665	4,111	1,839	4,539	1,287	3,177	2,429	4,319
Li-ion	777	1,918	858	2,118	600	1,482	1,133	2,015
NaNiCl	622	1,534	686	1,694	480	1,186	907	1,612
V-Redox	1,244	3,070	1,373	3,389	961	2,373	1,814	3,225
ZnBr	1,665	4,111	1,839	4,539	1,287	3,177	2,429	4,319
Zn-air	292	720	322	795	226	557	426	757

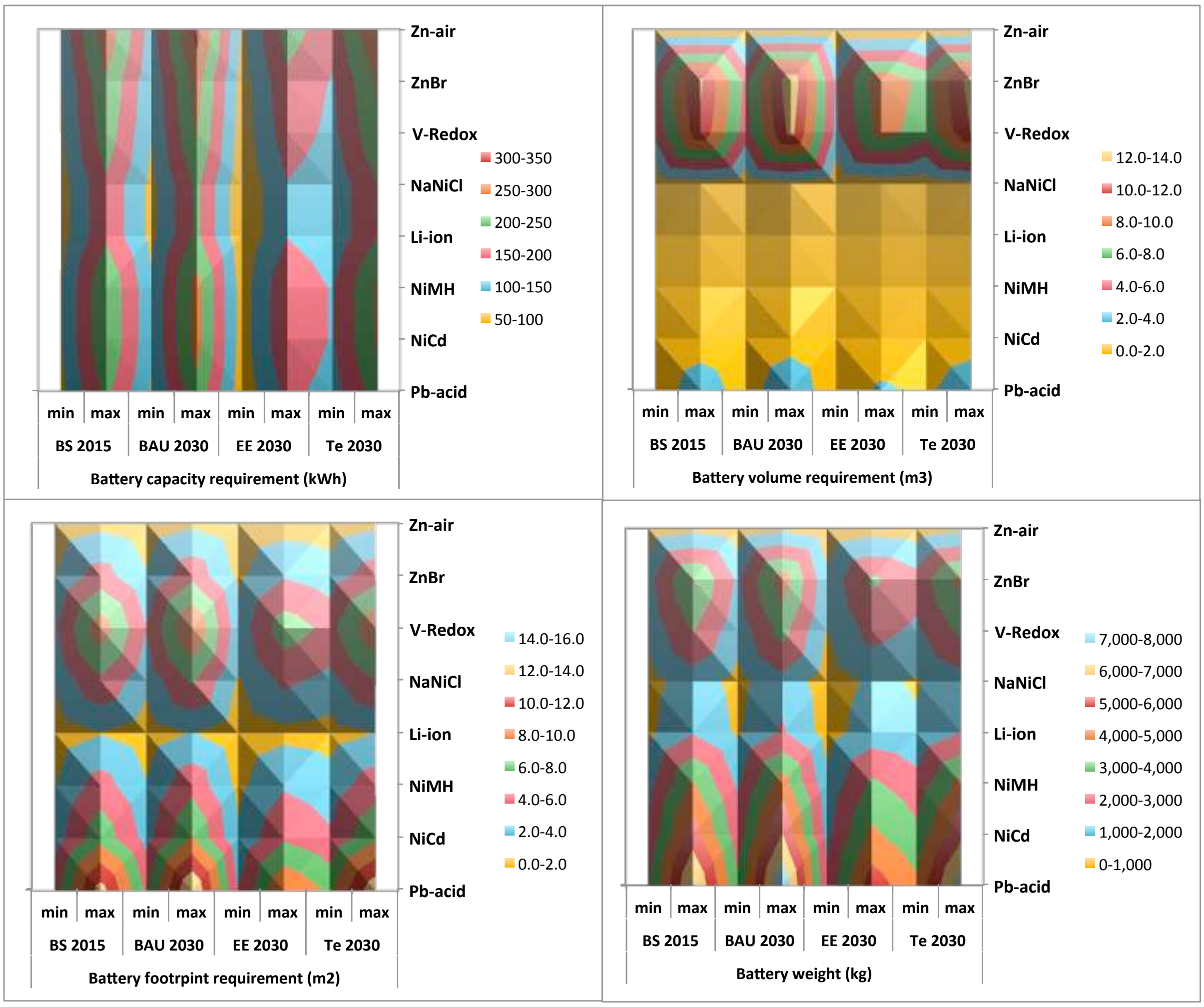

Figure 7: Storage capacity, footprint, volume and weight of the battery technologies in each scenario

The yellow colour in the four graphs presented above, which is associated with the lowest values, relates to the optimum solution as regards the characteristic described in each graph. The sky blue represents the next best option. For example, looking at the footprint requirement for an electrically heated house in all scenarios, Li-ion and Zinc-air batteries are the optimum solutions requiring very low space – up to about 2m^2 - and NiMH, NaNiCl and ZnBr come second with slightly higher footprints. Regarding the volume requirement, NiCd, NiMH, Li-ion, NaNiCl and Zn-air technologies score high, meaning they require very low volume up to 2m^3 in all scenarios, while Pb-acid batteries may require up to 4m^3 and V-redox and ZnBr up to about 14m^3. In terms of weight, Li-ion, NaNiCl and Zn-air technologies are the lightest option, weighting up to 2kg depending on the scenario and the electricity consumption of the house. The rest of the technologies are heavier and can weigh up to about 8kg. All in all, Li-ion and Zn-air batteries score high in all three characteristics and NaNiCl come second. Pb-acid and flow batteries are really unfavourable options in terms of both spatial requirements and weight.

Comparing the battery footprint to the average usable floor area of dwellings in the UK, which is 91m^2(Department for Communities and Local Government, 2010), batteries can generally occupy an area ranging from 1% to 12% of a dwelling's floor area depending on the scenario. Zn-air and Li-ion batteries, which are promising technologies as previously mentioned, occupy only about 1%-2% of a dwelling's floor area, while Pb-acid batteries, having a large footprint, can occupy up to 12% of it. The comparison of all technologies regarding this aspect is presented in **Figure 8**.

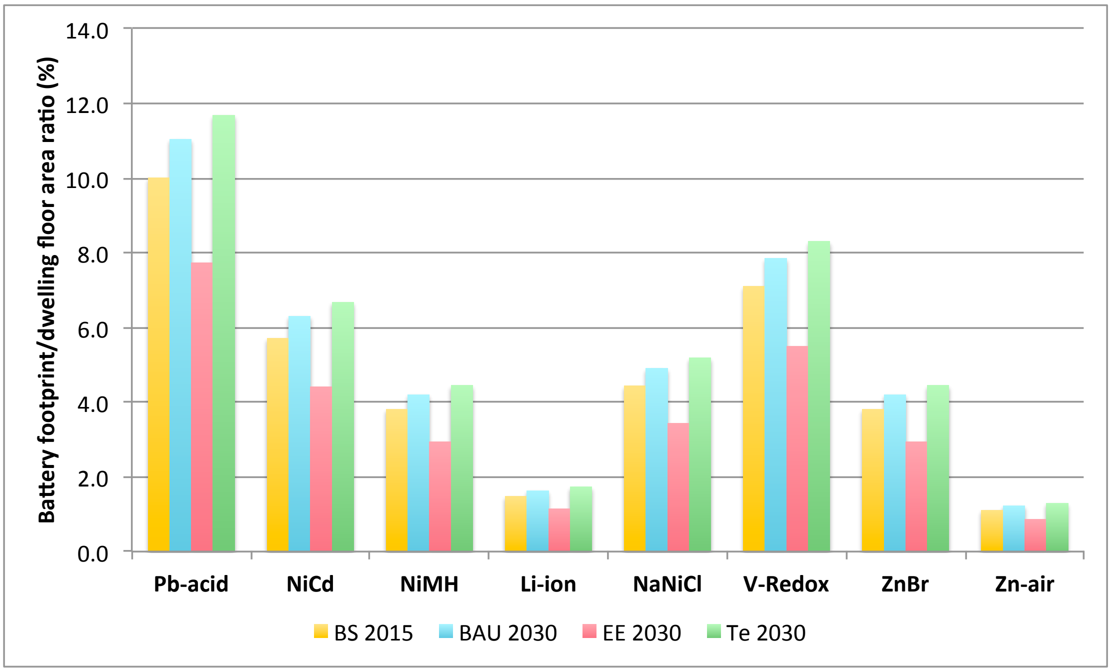

Figure 8: Comparison of ratio of average battery footprint to dwelling usable floor area in each scenario

For a better understanding of the volume required by each battery technology, a volumetric analogy is performed assuming a typical fridge. So assuming a fridge measuring 0.65m x 0.65m x 1.8m, the equivalent amount of fridges (volume-wise) required depending on the technology and scenario is presented in **Figure 9**.

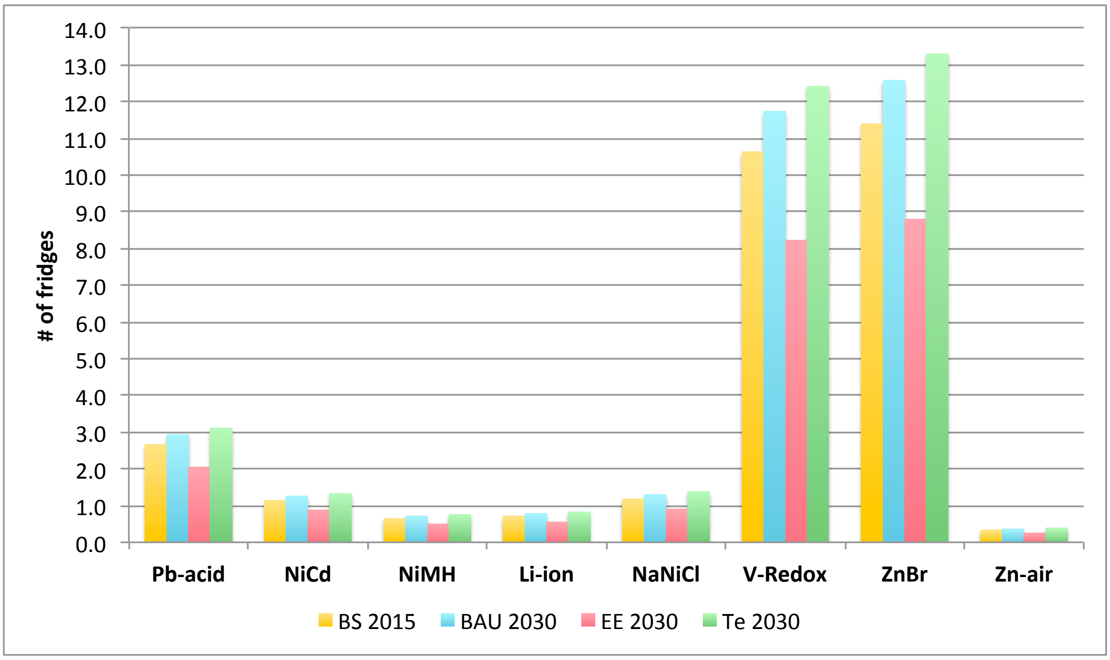

Figure 9: Volumetric analogy demonstrating the number of typical fridges required in each battery scenario

As shown in **Figure 9**, Li-ion and NiMH batteries would require the equivalent volume of about one typical fridge in the Te scenario, while the Zn-air technology would need half this volume. NiCd and NaNiCl batteries would require slightly higher than a fridge's volume in the same scenario, and Pb-acid would need the equivalent volume of three fridges. V-Redox and ZnBr technologies are way too inefficient in that respect, requiring over four times Pb-acid's volume, which is the equivalent volume of about 12-13 typical fridges.

3.3 Other considerations

The batteries can be installed in various locations according to the technology used and the availability of appropriate space. They shall be housed in protected accommodation, such as cabinets or enclosures inside or outside buildings. Typical locations include a cupboard along with the rest of the electrical equipment of the building, the loft, the roof, outside in a yard or in the ground (Steele and MacLeman, 2014). They should be protected from extreme environmental influences in terms of temperature, humidity and airborne contamination (The British Standards Institution, 2001). Appropriate ventilation must also be provided. This is because during the charge of the batteries, gases such as hydrogen and oxygen are emitted into the surrounding atmosphere, which might form an explosive mixture (The British Standards Institution, 2001). Moreover, it is essential that the battery installation gains social acceptance. It is, therefore, recommended that consultation from the people using the battery or the surrounding space be sought in advance. The users would also possibly need to change their habitual daily patterns regarding their electricity consumption and this can prove indispensable for the comfort of the occupants and the efficient operation of the system.

The eight battery technologies assessed in this paper present a great variety on their investment cost. Based on the cost per kWh provided in the paper authored by Chatzivasileiadi et al. (2013), the investment cost for a battery system able to supply an electrically heated household in the UK in Te 2030 scenario has been calculated and is presented in **Figure 10**.

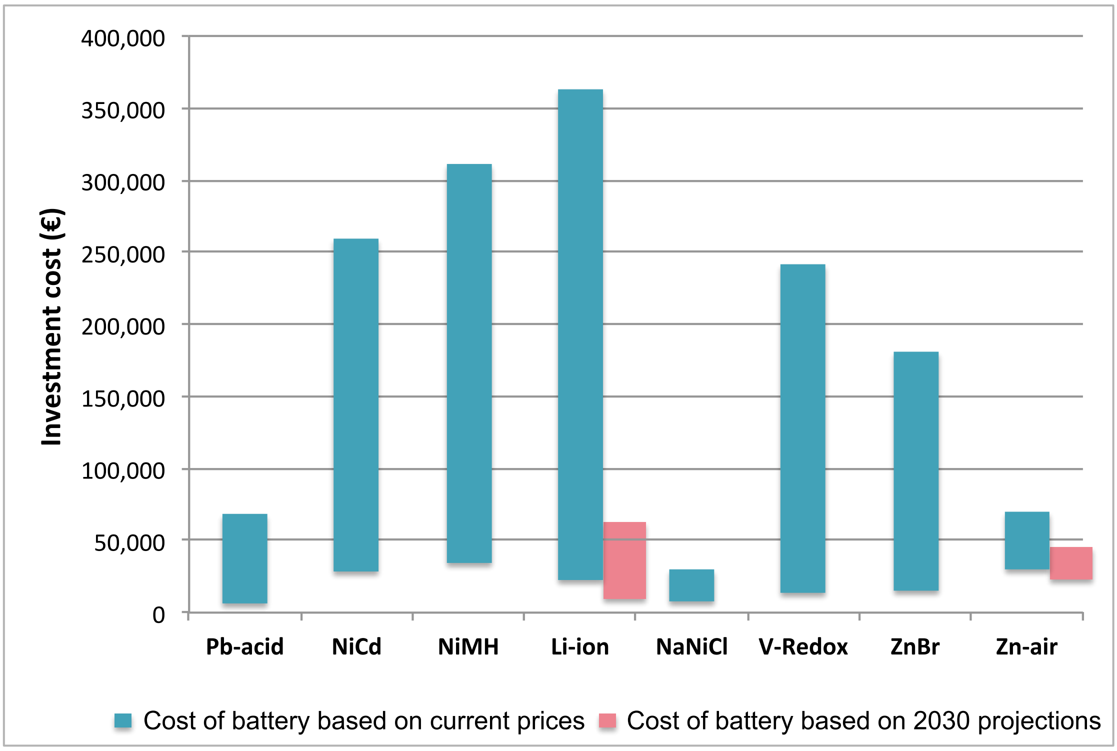

Figure 10: Battery cost associated with the battery capacity required in the Te 2030 scenario

The calculations have been performed using the current battery prices, as very few price forecasts are quoted in the literature or shared by battery manufacturers. So, according to Hoffmann (2014) and Beadsworth (2014) Li-ion battery prices are expected to decline to less than 300€/kWh in 2030. This fall will be driven by improvements in cathode/anode advanced material research coupled with mass production and industrialization of LI-Ion production. Similarly, Zn-air battery cost is projected to decline from currently 180-230€/kWh to about 150€/kWh in 2030 (Parkinson, 2013).

4. Conclusion

There is a great potential to reduce the carbon footprint of the built environment by managing electricity through energy storage. As EES technologies exhibit a large spectrum of performances and capacities, there is at least one solution currently available for each type of application or electricity storage scale. A number of design considerations regarding the EES' footprint, location, ventilation and safety should be taken into account prior to EES integration in buildings. Through the scenario modeling, it was found that Li-ion, Zn-air and NaNiCl battery technologies are currently the most favourable options for EES integration in buildings in 2030 due to their small footprint, small volume and low weight. In terms of cost, Li-ion batteries currently have the highest investment cost, but are expected to be a cost competitive option in 2030.

5. References

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